14 Apr 2004, 4:30 pm - 6:30 pm

# Instrumentation and Performance of Tied-Back Shotcrete Shoring in Sand Adjacent to a Hospital Structure

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Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

# INSTRUMENTATION AND PERFORMANCE OF TIED-BACK SHOTCRETE SHORING IN SAND ADJACENT TO A HOSPITAL STRUCTURE

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## ABSTRACT

Recent additions to the Brantford General Hospital expansion included construction of a new hospital wing, involving excavations of up to 11 metres (36 feet) depth, in loose to compact sand adjacent to an existing eight-storey hospital structure. The tendered contract called for interlocking caisson walls. An alternative method of temporary excavation support, tied-back shotcrete shoring, was proposed by HC Matcon Ltd. Due to a lack of familiarity with this method in Ontario, the uncertainty of attaining near-zero movements, and the proximity of adjacent 'lifeline' structures, the design-build team of HC Matcon and Isherwood Associates implemented a comprehensive program of quality control and assurance.

The instrumentation for this program included inclinometers, standard and precision visual survey, electrolytic tilt-meters, and load cells. The inclinometers were generally placed directly behind the wall faces to ensure accurate monitoring of the shoring face and effects of installation procedures. Precision survey was used to monitor shoring and structural displacements. Electrolytic tilt-meters (electrolevels) were placed on the adjacent structures' foundation walls and floor beams to ensure an accurate differential movement history of the structure at critical points. Frequent data acquisition from the inclinometers and electrolevels provided timely feedback and permitted accurate assessment of the performance of the shoring system during installation. It allowed for rapid response by the design-build team to any unexpected movements of the shoring or adjacent structures.

Movements of the shotcrete shoring face in the hospital wing phase of the project were limited to 3 millimetres or 0.03% of the shoring height - equivalent to that achieved by caisson wall in similar ground conditions. Of note, the adjacent hospital structures' movements were measured as less than 3 millimetres, better than expected from a caisson wall system due to ground loss problems often associated with large diameter vertical and horizontal drilling. The excellent performance of the shotcrete shoring in the hospital wing phase was attributed to shoring design features, good workmanship, and rigorous quality control efforts by the design-build team. The monitoring results allowed for 'real time' reaction.

## INTRODUCTION

At Brantford General Hospital (BGH) in Brantford, Ontario, an excavation up to 36 feet deep in a native, loose to compact, normally consolidated sand deposit was supported with tied-back shotcrete. Structures up to eight stories high were situated immediately adjacent to the excavation; see Figure 1. The BGH site is located on a major sand deposit. The geotechnical report indicated the sand was usually fine, grading to fine to medium, with a moisture content of 1 to 9 percent. Grain size distribution curves for the soil are shown in Fig. 2. Standard penetration test (SPT) and dynamic cone penetration test (DCPT) results indicated the sand was loose to compact near the surface, becoming increasingly compact with depth, and are summarised in Table 1.

For protection of the adjacent buildings, the design-build team set a 6 millimetre target limit on shoring deflections. To meet the movement control objectives, an approach was developed which involved soil face protection measures, a detailed tieback stressing program, and monitoring. For monitoring purposes, the site was instrumented with inclinometers, electrolevels, load cells, and survey targets on shoring and adjacent structures.

Monitoring data indicated shoring wall movements were limited to a maximum of approximately 3 millimetres into-site, half the target limit. The excavation was completed on schedule, with savings of 20 percent over a conventional shoring solution.

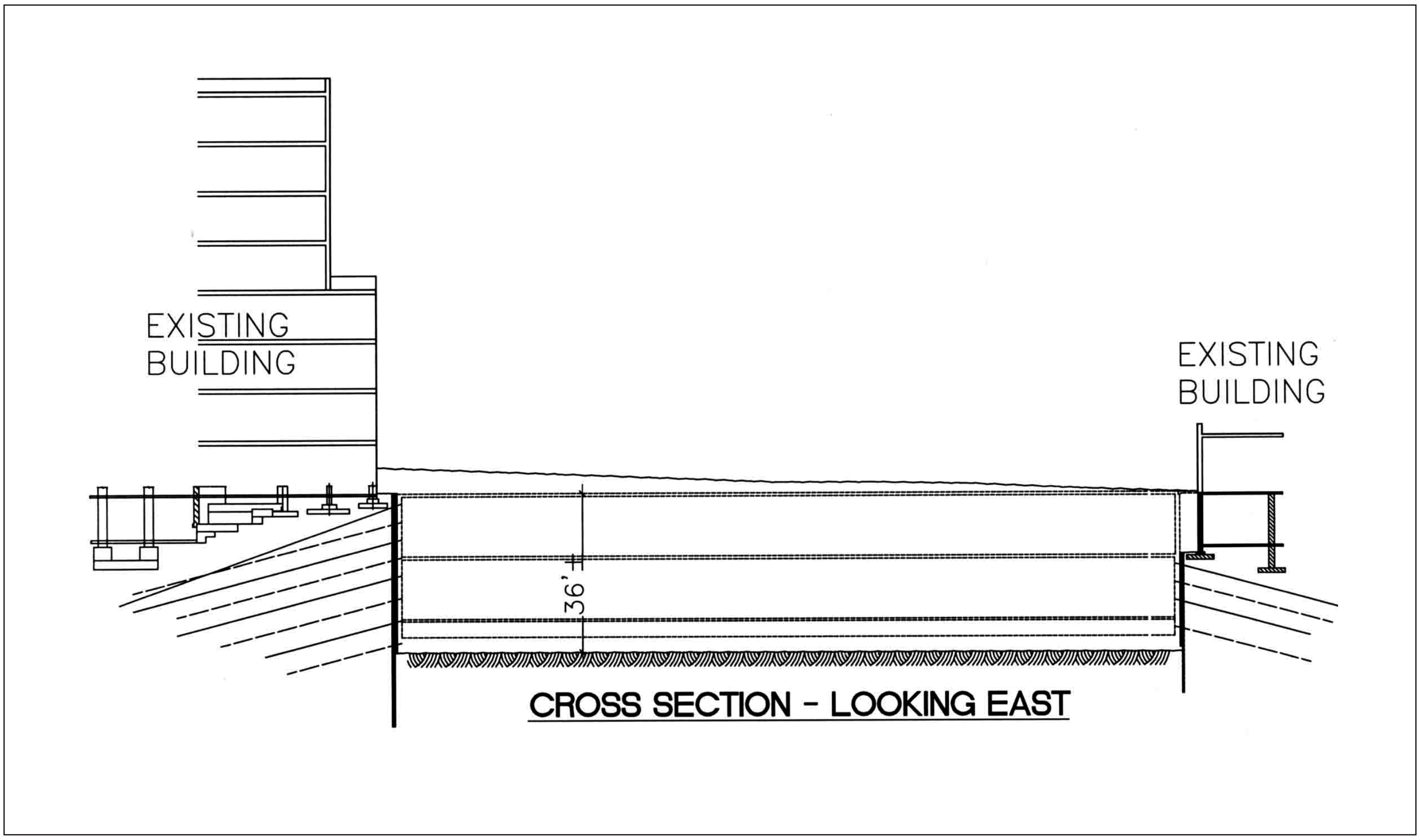



*Fig. 1. Cross Section of Site*

ADVANTAGES OF TIED-BACK SHOTCRETE SHORING ON THE BGH PROJECT

The impetus to use tied-back shotcrete shoring was potential cost savings, arising mainly from lower material costs, and economies related to the use of light construction equipment, site-deployed with relative ease. Compact and versatile, the installation equipment was ideal for coping with existing grades as steep as 3 horizontal to 1 vertical, and working in close proximity to adjacent buildings.

Small-diameter tieback installation through berms with self-drilling hollow bar meant negligible impact on the soil mass. Relatively low construction vibrations reduced the potential for settlement of adjacent hospital foundations supported on the sand deposit and disruption of hospital services, such as surgeries. Construction activities causing noticeable vibrations would have been halted by the hospital administration on a routine basis.

Smaller equipment, lower concrete volumes, fewer compressors, and less truck traffic contributed to lower dust and pollution levels, a significant hazard in a hospital environment, particularly in facilities treating transplant patients or patients with respiratory difficulties.

Tied-back shotcrete walls were approximately 20 percent of the thickness of conventional shoring walls.

Excavation to final grade was completed sooner, since it was carried out simultaneously with shoring construction. Although the excavation process was less efficient, the general contractor was able to get a head start on foundation construction.

Shoring modifications were relatively easy to effect during construction due to the inherent flexibility of the shotcrete method.

APPROACH TO MOVEMENT CONTROL

Uncertainty existed regarding the level of deflection control that could be achieved using tied-back shotcrete in the type of soil on the BGH site. Lack of precedent and monitoring data was a source of concern to all parties. The design build team was responsible for system performance and considered proper handling of the non-cohesive, vibration-sensitive soil a challenge key to limiting ground movements. The following measures were taken to minimize exposure time and disturbance of the soil excavated for shotcrete application.

- Excavation was carried out using a 3-panel sequence where buildings were remote from the excavation, and a 4-panel sequence at buildings.

- Berms with 1-metre ledges were left in place during tieback drilling. Berm maintenance included watering during windy or dry conditions.

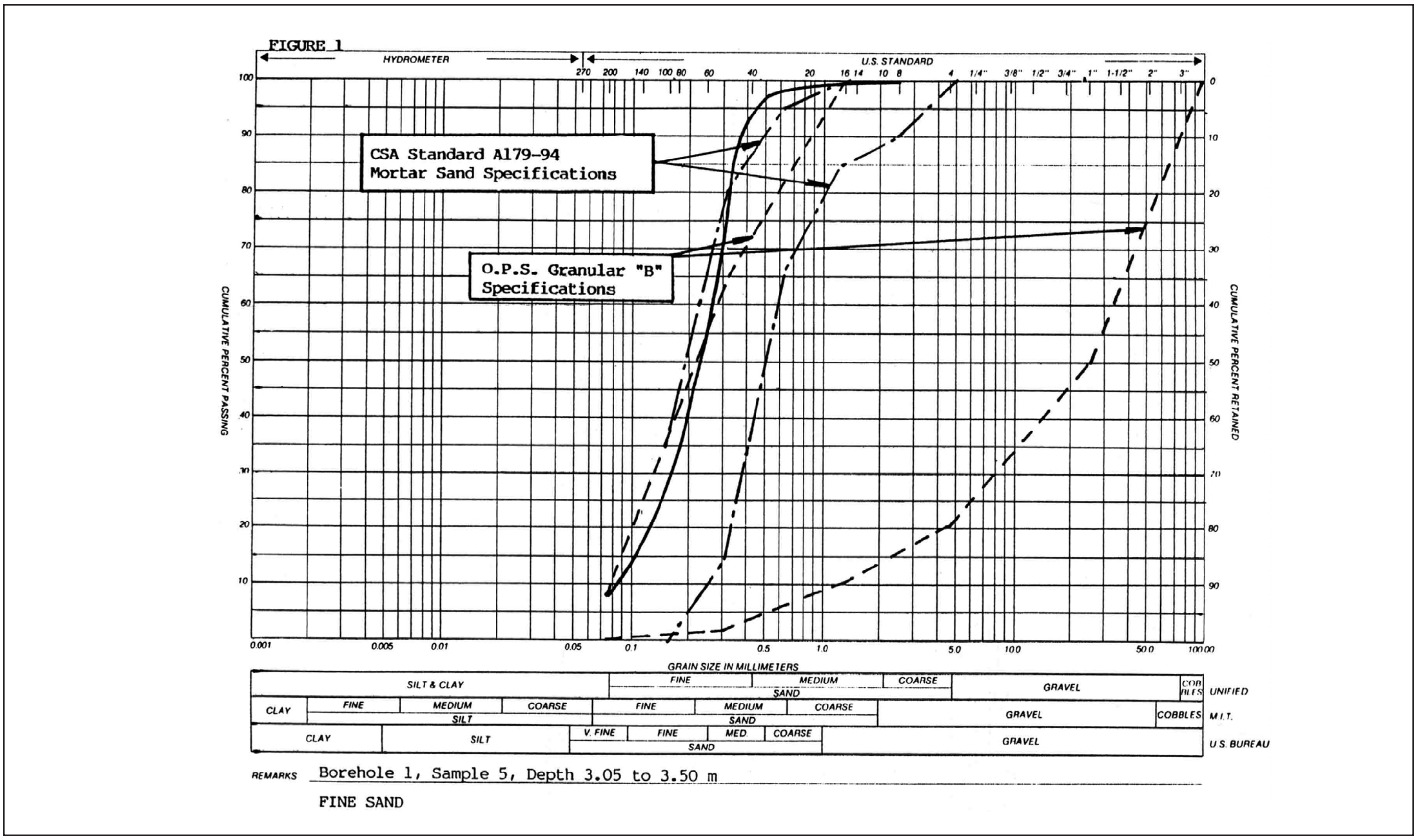



*Fig. 2. Grain Size Distribution Chart [1]*

Table 1. Soil Testing Data

| Location | Type of Test | Blows/ft |
|---|---|---|
| Upper 4m | SPT | 6 to 20 |
| | DCPT | 4 to 23 |
| Below 4m | SPT | 12 to 24 |
| | DCPT | 15 to 63 |

- Shotcrete panel construction was completed the same day berms were removed.
- Vertical dowels, consisting of steel bars in 3 inch drilled holes, were installed at the shoring line prior to the start of excavation. The dowels, approximately 3 per panel, provided temporary face support during excavation and shotcrete application.
- Dowels in 8 inch holes on 4 foot centres augmented the smaller dowels at the most critical part of the excavation, to provide vertical support for the shoring wall should ground loss occur.
- To minimize ground loss potential, self-drilling hollow (MAI) bars were installed and grouted to surface with sleeves to obtain design free zone lengths. Tiebacks were partially stressed the morning after panel construction, and fully stressed prior to excavation of the next lift.

## TIEBACK STRESSING PROGRAM

### Proof-tests

All tiebacks were proof-tested by cyclic loading to check free length and anchor performance. Early in the project, it was noted that elongation values in a significant number of proof tests indicated less-than-design free lengths. Where this occurred, the tests were repeated using higher proof loads to break bonds and mobilize longer free zones.

Proof testing showed 99.5 percent of tiebacks met anchor capacity requirements. Tieback anchors that could not resist the proof load were replaced.

### Lift-off tests

Lift-off tests were performed wherever loss-of-load was suspected, and to ensure inspection records were complete. In total, 4 percent of tiebacks were lift-off tested, and test results generally confirmed expectations. Seven random lift-off tests, conducted on upper level tiebacks when excavation depths were

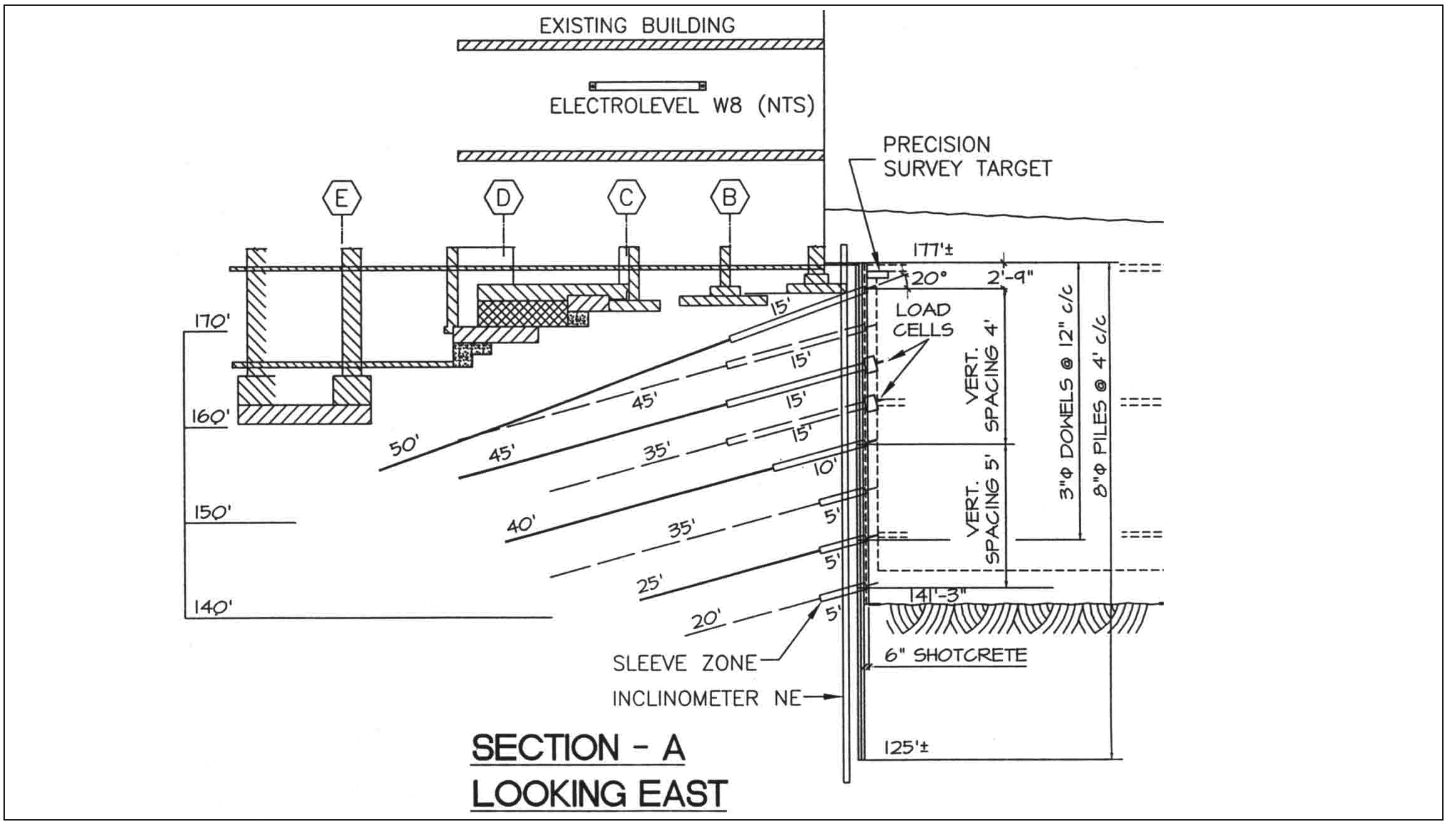



*Fig. 3. Section A*

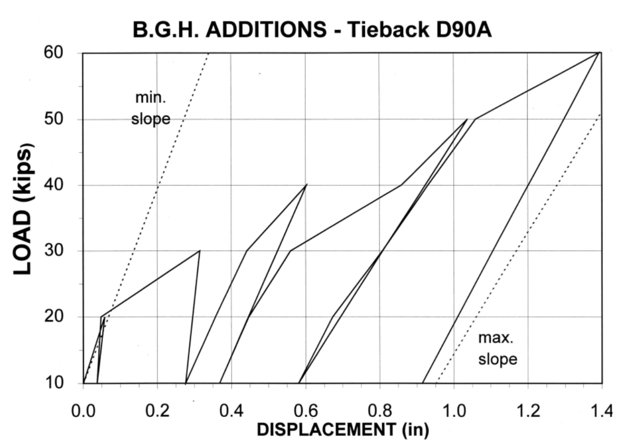
20 to 25 feet, indicated tieback loads were 86 percent of design load on average.

Load cell readings

Load cell data was obtained from two locations, as shown in Fig. 3. At the third and fourth tieback rows, load cell readings indicated tieback lock-in values were 110 and 114 percent of design load respectively, and initial load losses were 18 and 22 percent of lock-in values respectively. With both load cells in place, the remaining 20 feet of soil was excavated in 45 days and additional load losses of approximately 5 percent of lock-in value were measured. Final load cell readings, taken one month after excavation was completed, indicated tieback loads were approximately 84 percent of design load.

Performance tests

Four tieback performance tests were carried out. Three production anchors, with bond lengths ranging from 22 to 54 feet, were tested initially. At the maximum test load of 60 kips, anchor forces ranged from 1.1 to 2.6 kips/feet. The fourth test, carried out on a non-production tieback with the bond length shortened for testing purposes, demonstrated an anchor adhesion capacity of 7.3 kips/feet. The test data are plotted in Fig. 4. The ultimate capacity of the tiebacks was not determined.




1. Minimum slope based on 80% sleeved length + jack length
2. Maximum free length based on 50% anchor length + sleeved length + jack length

*Fig. 4. Performance Test Plot*

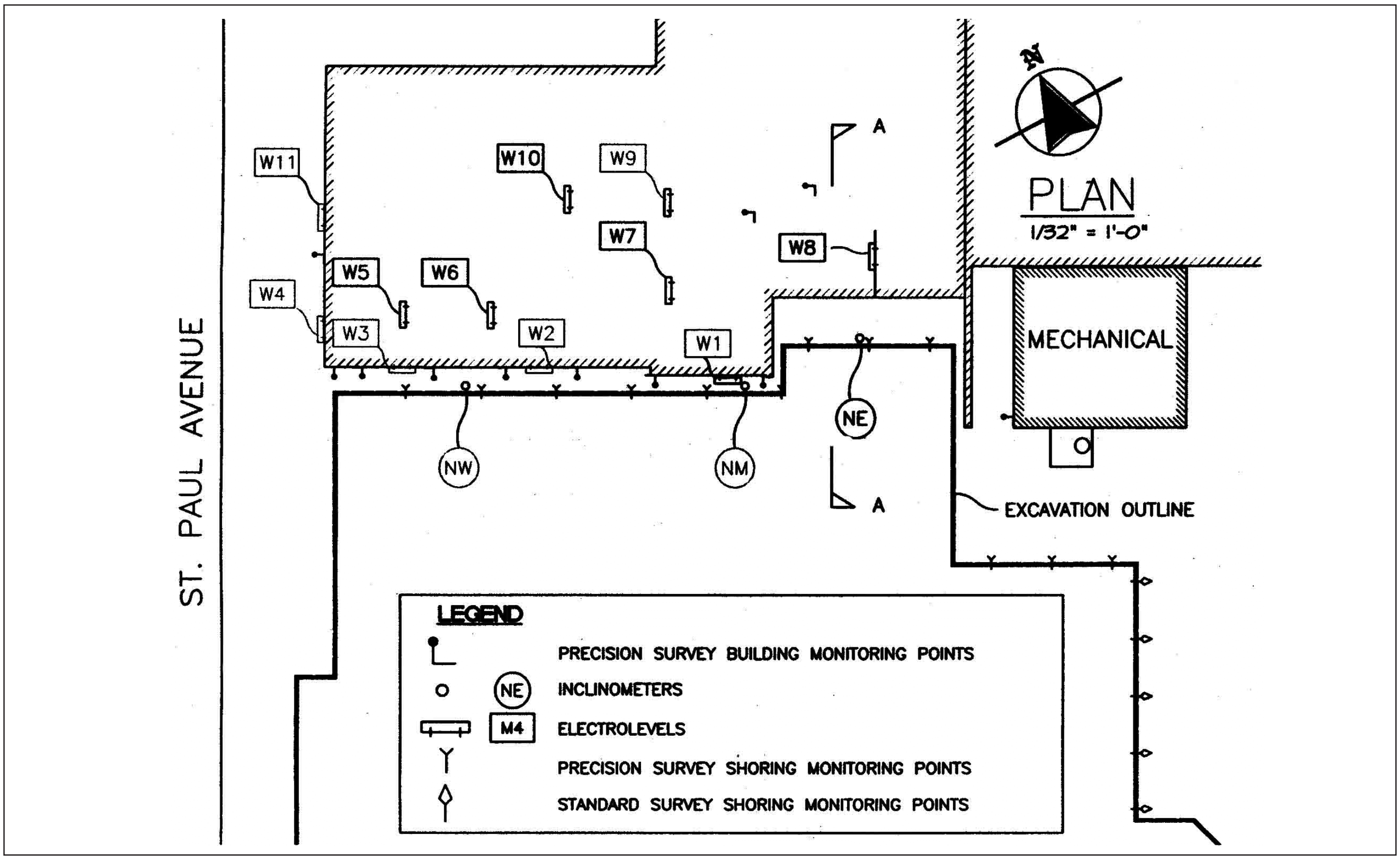



Fig. 5. Monitoring Instrument Locations

MONITORING PROGRAM

Several forms of monitoring were used to track shoring performance during construction (see partial plan in Fig. 5). A total of eight inclinometers were installed on cuts greater than 16 feet deep, and were concentrated at buildings. Electrolevel installations, totalling sixteen, were located on hospital foundation walls and beams. Precision survey data was collected from thirty-two targets on shoring walls at 3-metre centres, and sixteen targets at strategic points on adjacent structures.

Inclinometers were read weekly, and results were checked the same day. Electrolevels were read several times a week initially, to observe how the data fluctuated, and were read at least once a week until shoring installation was completed. Baseline precision and standard survey readings were recorded and available for comparison with other monitoring data.

MONITORING RESULTS

Inclinometers

The deepest part of the excavation coincided with the highest part of the hospital structure and was instrumented with precision survey targets, an inclinometer (NE), an electrolevel (W8), and two load cells. See Fig. 3 and Fig. 5 for section and plan views respectively.

Inclinometer plot NE, displayed in Fig. 6, showed characteristic into-site "bulges" concurrent with excavation of each lift. The time period between lifts, from initial berm excavation to final tieback stressing varied from four to fourteen days. The plot indicates maximum displacements or “bulges” were localized in areas of active excavation near the base of the cut. Above the active lift, where shotcrete application and tieback stressing had been completed, displacements were negligible; note less than 1 millimetre of movement occurred at the top of the wall between October 4 and December 12.

Upon completion of all excavation and shotcrete wall construction, the maximum relative into-site displacement was 2.2 millimetres. Additional post-excavation displacements, mainly attributed to compaction vibrations, increased the maximum displacement to 3.3 millimetres or 0.03 percent of the excavation depth.

Electrolevels

The electrolevels used on the BGH project consisted of beams, generally 1m long, containing an electrolytic tilt sensor, which outputs a voltage proportional to the tilt of the sensor. A diagram of the sensor is shown in Fig. 7.

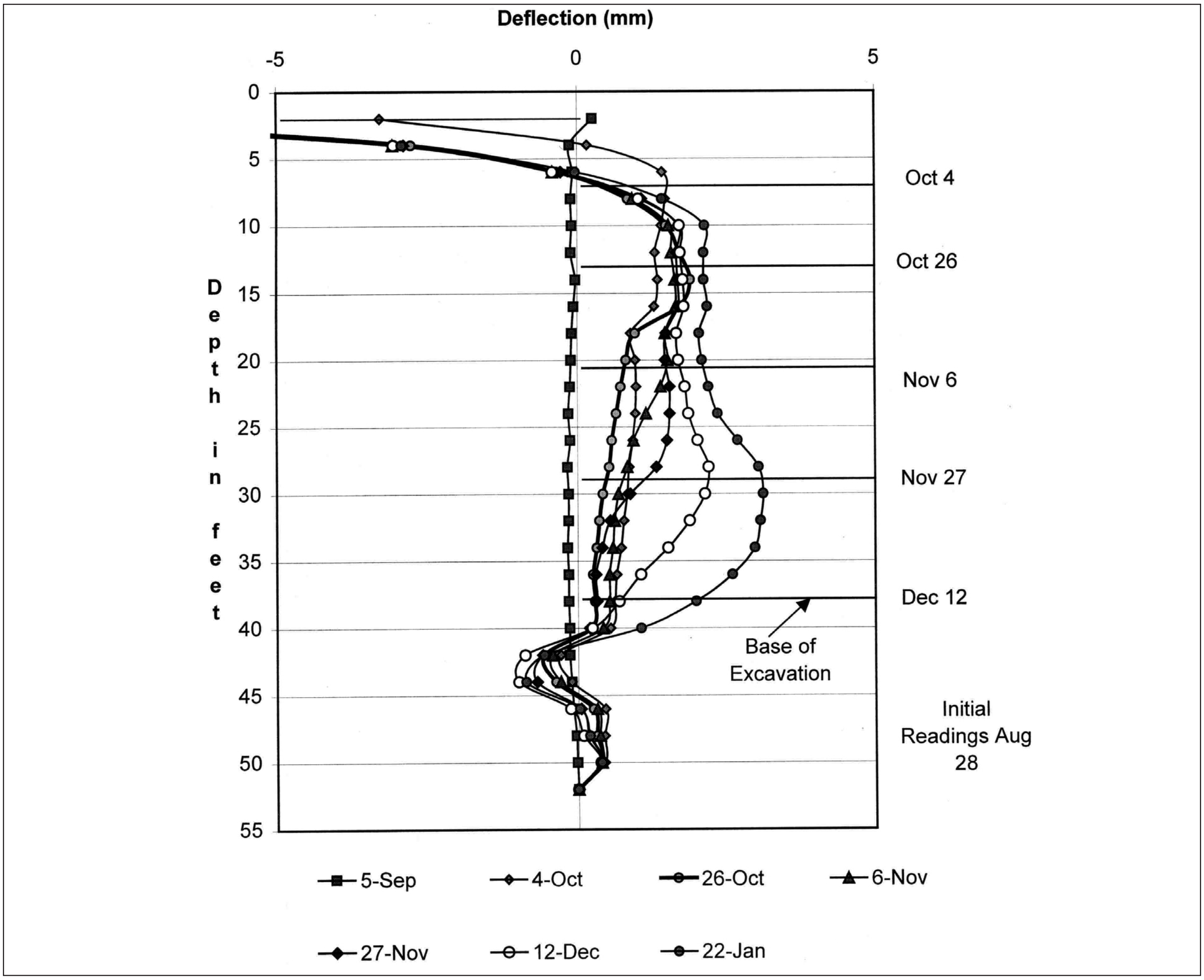



*Fig. 6. Displacement Plot for Inclinometer NE*

The electrolevel beams were levelled and fixed to concrete surfaces with anchor bolts, and then the sensors were levelled to give baseline readings of zero.

Electrolevel readings from instrument W8 at section A (Fig. 3) and four other instruments installed inside the hospital building are presented in figures 8 and 9 respectively. Examination of the plots reveals that the readings are sensitive to temperature fluctuations.

Changes in relative displacement over a one-metre electrolevel beam length ranged from 0.2 to 0.7 millimetres, without temperature calibration, upon completion of the excavation. Considered over the span of the walls or beams supporting the instruments, the readings suggested average total building displacements ranging from 0.7 to 3.6 millimetres. However, factoring in the temperature effects, displacements were more realistically on the order of 0 to 0.4 millimetres.

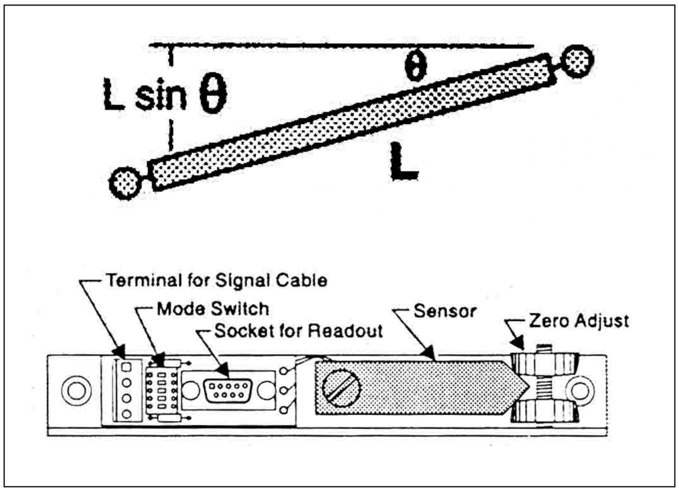



*Fig. 7. Electrolevel Sensor Diagram - Slope Indicator [1996]*

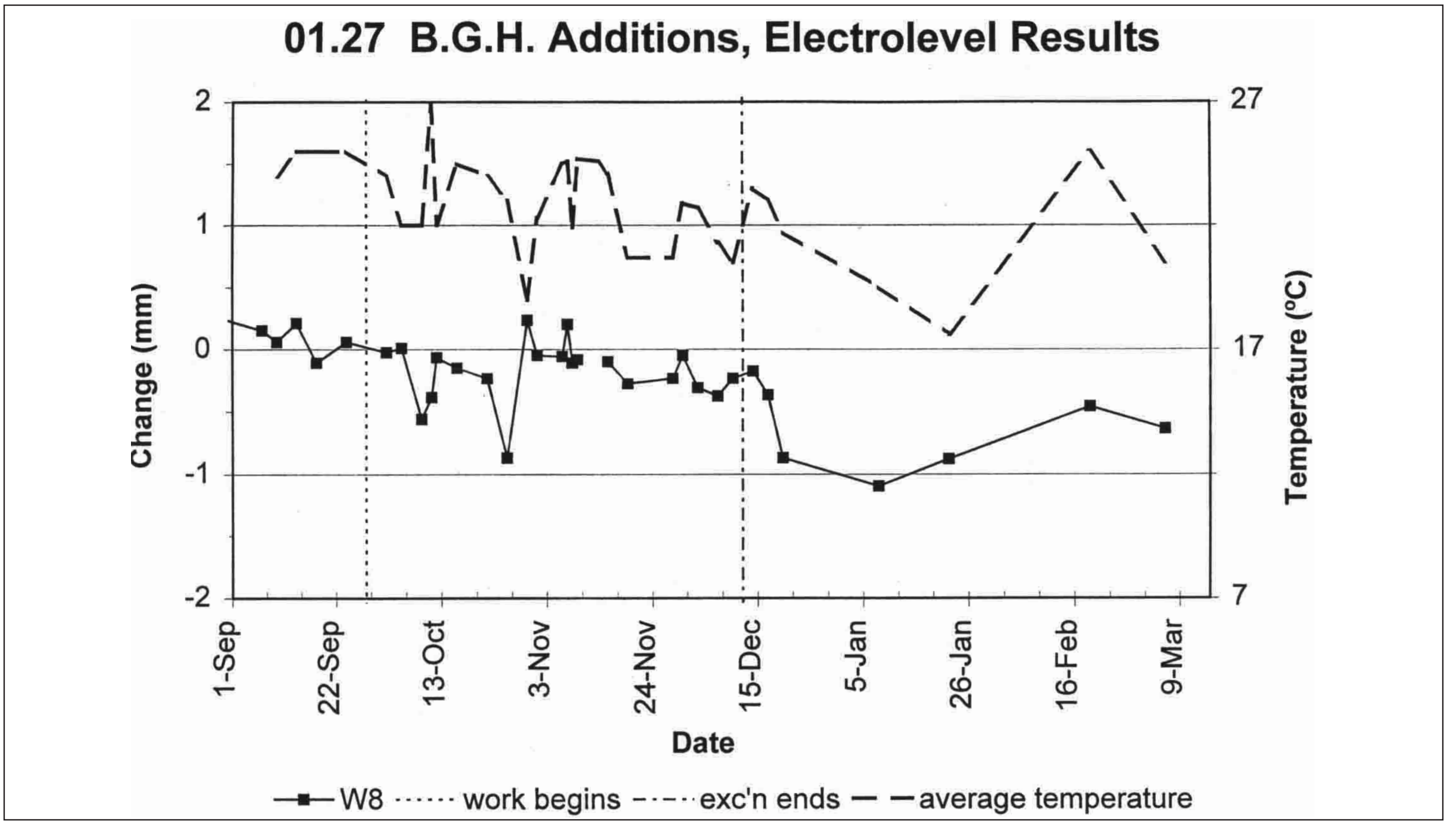



*Fig. 8. Electrolevel Results*

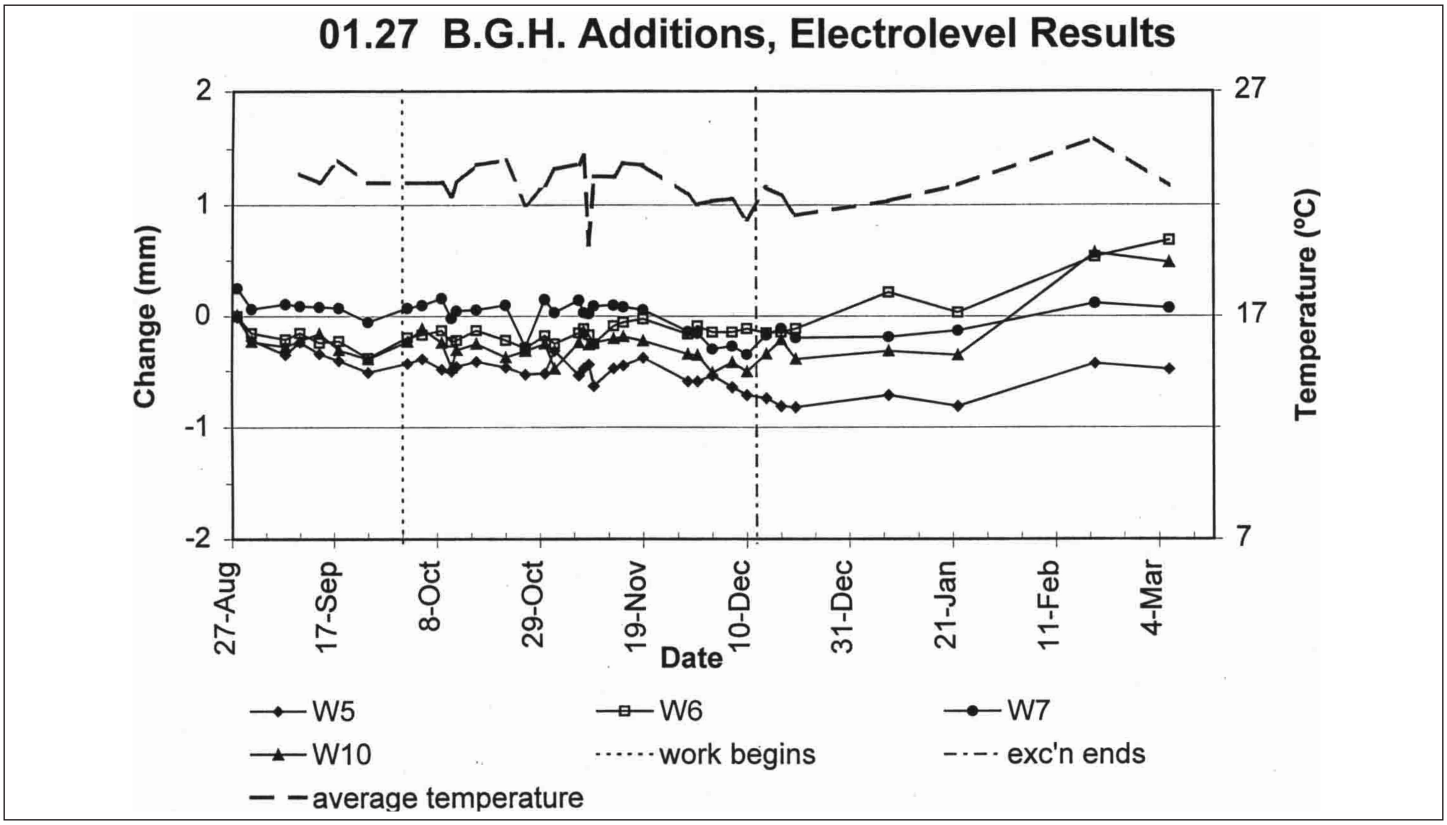



*Fig. 9. Electrolevel Results at Section A*

Precision surveying

Unlike the other forms of monitoring on the site, precision survey readings were based on a geodetic datum. At section A, shown in Fig. 3, building target readings indicated a maximum horizontal displacement of 3 millimetres into-site, and maximum vertical displacement of 1 millimetre down. Shoring target readings indicated 1 to 2 millimetres horizontal displacement into-site, and vertical displacements between 1 millimetre down and 3 millimetres up.

## CONCLUSIONS

Inclinometer and electrolevel readings, confirmed by precision survey readings, indicated ground movements were limited to 0.03 percent of the height of the cut, and building settlements were limited to 1 millimetre. Based on shoring performance at the BGH site, tied-back shotcrete can be used in essentially normally consolidated, fine to medium grained, loose to compact sand to achieve near-negligible ground and adjacent structure movements.

On the BGH site, soil face protection measures and a suitable tieback stressing program were effective in assisting ground movement control. Tieback testing and monitoring helped confirm design and construction methodology on a timely basis, and furnished valuable data on wall and anchorage behaviour. Monitoring also increased the comfort level of all concerned parties.

Higher-than-anticipated ultimate anchor adhesion capacities in the sand could be capitalized on with further testing and experience working with tied-back shotcrete in this type of material. As the matrix of the composite shoring wall, the sand exhibited suitable characteristics, as evidenced by the inclinometer data indicating movements were only minor or negligible.

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